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NAVAL POSTGRADUATE SCHOOL
Monterey, California

SPECIFICATIONS FOR THE PRODUCTION OF
OCEAN WAVE STATISTICS
FOR THE CALIFORNIA COAST
FROM FNWC SINGULAR WAVE ANALYSES

by

Warren C. Thompson

March 1976

Final Report on Objective (a)

Prepared for:

Department of Navigation and Ocean Development
State of California
Sacramento, California 95814

Approved for public release; distribution unlimited.

NAVAL POSTGRADUATE SCHOOL
Monterey, California

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20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*
Specifications are presented for the production of ocean wave statistics for the California coast from approximately 28 years of archived synoptic wave analyses computed by the Fleet Numerical Weather Central, Monterey, California. The wave statistics, designed for coastal engineering application, would be prepared for six deep-water stations uniformly spaced along the coast from the Oregon border to the Mexico border, and would be prepared in the form of desk-top copy immediately available for use.

PREFACE

This report is produced under State of California Standard Agreement 5-42-96-22 with the Department of Navigation and Ocean Development, State of California, 1416 9th Avenue, Sacramento, California 95814. The specifications presented herein satisfy the first objective of the two-part contract proposal concerned with the development of ocean wave statistics for the coastal waters of California to be derived from archived synoptic wave analyses produced by the Fleet Numerical Weather Central (FNWC), Monterey, California. The objectives of the proposal are quoted as follows:

a. To prepare specifications for the production of ocean wave statistics for the coast of California from singular wave analyses contained in the archives of FNWC.

b. To develop a procedure for compiling ocean wave statistics from the spectral wave analyses now being produced by FNWC.

FNWC issues wave analyses and forecasts at 12 hourly intervals for a grid-point array covering the major oceans of the Northern Hemisphere. Only the wave analyses are suitable for the computation of wave statistics. The analyses are made from the surface wind field which, in turn, is derived from the real-time sea level pressure field fitted to pressure observations made at 6 hourly synoptic reporting times over the Northern Hemisphere; forecasts are derived from forecasted pressure fields by a similar procedure.

For the period from 1946 to 1974 the Sverdrup-Munk-Bretschneider (SMB) sea-generation model in modified form was used by FNWC to generate the waves from the surface wind field. The wave analyses produced using this model are termed "singular" analyses by FNWC personnel to distinguish them from spectral analyses derived from a spectral generation model. Singular refers to the fact that at each ocean grid point at a given synoptic time the computed waves, both sea and swell, are described by a single significant height, period, and direction, as though a monochromatic wave train were present. In the singular computer program, sea is generated independently of any swell present, and both sea and swell are reported separately for each grid point.

Approximately 28 years of singular synoptic wave analyses for the Northern Hemisphere are stored on computer tapes in FNWC. The specifications for converting this synoptic information into climatological wave statistics for coastal engineering use on the California coast are presented in this report.

In December 1974 the singular wave model was replaced operationally in FNWC by the spectral ocean wave model (SOWM). This model is used to produce 12 hourly at Northern Hemisphere grid points both analyses and forecasts (to 72 hours) of the wave energy contained in 15 frequency bands and 12 direction bands, giving a total of 180 energy components. This spectral information is also summarized in the form of a single significant height, period, and direction. Seas are generated on top of the swell energy that is present, and sea and swell are not differentiated in the spectral or singular printouts.

The second objective of this research proposal, to be presented in a subsequent report, will be concerned with the design of wave climatology formats suitable for the California coast derived from FNWC spectral ocean wave analyses.

WARREN C. THOMPSON
Principal Investigator
31 March 1976

SPECIFICATIONS FOR THE PRODUCTION OF OCEAN WAVE STATISTICS FOR THE CALIFORNIA COAST FROM FNWC SINGULAR WAVE ANALYSES

Prepared by Prof. Warren C. Thompson
Department of Oceanography, Naval Postgraduate School
Monterey, California 93940
for the
Department of Navigation and Ocean Development (DNOD)
1416 Ninth Street, Sacramento, California 95814

22 March 1976

OBJECTIVE

The ocean wave statistics prepared by National Marine Consultants (NMC) in 1960 and Marine Advisers (MA) in 1961 that are currently in use on the California coast were derived from three years of synoptic weather maps. DNOD is preparing to increase this 3-year data base through the production of additional wave statistics to be compiled from 25 to 28 years of Fleet Numerical Weather Central (FNWC) synoptic singular wave analyses. These statistics, to be prepared for selected deep-water stations extending from the Oregon border to the Mexico border, will be designed specifically for coastal engineering application. The working steps and technical specifications presented herein provide the guidelines to accomplish this task. These specifications were prepared in satisfaction of

Objective (a) of the Naval Postgraduate School proposal entitled Ocean Wave Climatology for the California Coast funded under State of California Standard Agreement No. 5-42-96-22. Objective (a) states: "To prepare specifications for the production of ocean wave statistics for the coast of California from singular wave analyses contained in the archives of the Fleet Numerical Weather Central (FNWC), Monterey, California".

WORK STEPS

1. Develop and test the following computer programs:
   a. Program to compile ocean wave statistics at selected deep-water coastal stations from archived FNWC tapes of synoptic singular wave analyses.
   b. Program to extend the wave information from FNWC grid points to selected deep-water wave stations along the California coast.
   c. Program to handle land-limited wave generation.
   d. Program to convert wave height units from feet to meters. (optional)
2. Produce camera-ready computer printouts of wave statistics ready for publication.
3. Write an accompanying text to include:
   a. Background information on the generation of the FNWC singular wave analyses.

b. Meteorological aspects of the ocean wave regime on the California coast. (optional)

c. Explanation of the statistical tables, and instructions or guidelines for their use.

d. Limitations to use of the wave statistics resulting from pecularities of the FNWC singular wave program, meteorological factors, and geographical factors.

4. Publish the following information for general and limited issue:

a. Publish for general use the following statistical data with full accompanying text (one station to a volume):

(1) Long-term average month and average year tables (see Section 4a(1)).

(2) Extreme occurrence tables (see Section 4a(3)).

(3) Wave height duration chronology graphs (see Section 4a(4)).

(4) Extreme wave event listing (see Section 4a(5)).

b. Publish separately a limited issue of specific month and specific year tables (see Section 4a(2)); include an abbreviated text covering construction, use, and limitations of the tables.

c. Publish separately or provide to DNOD and FNWC, for future public use, complete copies of all computer programs and routines developed to produce the wave climatology.

TECHNICAL SPECIFICATIONS

1. Wave data source

   Compile the wave statistics from the Northern Hemisphere singular wave analyses (not forecasts) produced by FNWC over the period 1946-1974 archived on magnetic tapes at FNWC Monterey.

2. Wave data selection

   FNWC placed their sea/swell model into routine operation in 1964 and replaced it in December 1974 by a spectral wave model. Numerous procedural changes in the model were made during the 10-year period, and these largely undocumented changes undoubtedly produced operational wave analyses of variable quality. The operational analyses also contain missing days and some incorrect input data. About 1971 Mr. Norman Stevenson of FNWC reprogrammed the singular wave model and applied it to historical wind-field analyses of good quality to produce hindcasted wave analyses for the 25-year period 1946-1971. The operational analyses for the period 1971-1974 were produced from operational wind-field analyses using Stevenson's program. The hindcasted wave analyses (1946-1971) are considered to be superior in quality to the operational wave analyses produced from 1964 to 1971, but have the shortcoming of being 24-hourly analyses computed by 24-hour time steps. In view of these considerations, the following recommendations are made regarding selection of the wave analyses from which to derive wave statistics: (1) For the years 1946-1971 use the FNWC hindcasted 24-hourly wave analyses; (2) For the years 1971-1974 select one of the following options: (i) omit these 3 years, (ii) use only the 24-hourly analyses for these 3 years, and (iii) use the 12-hourly analyses. Option (i) should be elected if time gaps or other complications arise from examination of the tapes for this period; these 3 years might be discarded solely on the basis that the wave analyses were derived from operational wind analyses which are of somewhat lower quality than the historical wind analyses for 1946-1971. The choice of Option (ii) versus Option (iii) would simplify manipulation and presentation of the wave statistics and would avoid their possible misuse. If Option (iii) is elected, the 12-hourly and 24-hourly analyses should not be mixed in compiling statistics (except as noted in Section 4a(4)) because of the fact that the analysis interval controls the computation of frequency of occurrence (see Section 4d). Statistics for a given period of time (e.g., a specific month, all years of a given month, a specific year, etc.) should be derived from those analyses of the shortest time interval available throughout the period; each climatological table should be labelled for the analysis interval used to produce it.

3. Coastal stations

a. Station locations: Compile wave statistics for the coastal sites shown in red on the attached map. The stations from Pt. Conception northward coincide with NMC stations; the stations southerly of Pt. Conception lie over the Patton Escarpment in deep water outside the influence of all banks and islands and do not coincide with NMC/MA stations. Examination of the NMC (1960) data shows that the deep-water wave climate gradient along the California coast for the NMC station interval is relatively small so that this spacing appears adequate for all practical uses; stations intermediate between those shown on the map could be added if desired but this would double the volume of the wave statistics.

b. Data extrapolation: The FNWC singular wave analyses are available only at FNWC grid points also shown on the attached map. These grid points do not coincide with the coastal station sites recommended; accordingly, extrapolation of the wave information must be made from the grid points to the stations. This can be accomplished either by (1) first extrapolating the synoptic wave height-period-direction (H-T-ψ) field for each analysis time from grid points to stations and then compiling the frequency-of-occurrence statistics from this time series, or (2) first compiling frequency-of-occurrence statistics at the FNWC grid points and then extrapolating this climatology field to the coastal stations (taking care to handle the extrapolated frequencies properly). In either case, the information to be compiled at the grid points should cover a region at least 2 grid points wide along the entire coast; this two-dimensional information field in space can then be extended by a suitable extrapolation equation to the selected coastal stations.

c. Land-limited wave generation: Waves arriving at coastal stations from all oceanward directions and parallel to shore should be included in the statistical compilations; waves arriving from shoreward directions should be excluded (the FNWC singular wave analysis program did not generate these waves adequately). Wave directions accepted and rejected must be determined for each station individually from consideration of the coastal configuration in the region of the station.

4. Data presentation formats

a. Climatological compilations: The following compilations should be prepared for each coastal station. The tables listed under (1), (2), and (3) should be presented in a format similar to the widely used tables published by National Marine Consultants (1960); an example is attached.

(1) Long-term mean frequency-of-occurrence tabulations derived by averaging over all of the complete years available.

(a) Average month tables (like NMC (1960) Tables 1.1 through 1.12): 12 tables per station.

(b) Average year table (like NMC (1960) Table 1.13): 1 table.

(2) Specific month/year frequency-of-occurrence tabulations (no NMC counterpart).

(a) Specific month tables (e.g., April 1964): Number of tables equals the number of full months available.

(b) Specific year tables (e.g., 1959): Number of tables equals the number of complete years available.

(3) Extreme frequency-of-occurrence tabulations: These are artificial occurrence tables showing the largest and smallest frequency of occurrence values contained in the tables of Section 4a(2) for each H-T-ψ increment occurring over all years (no NMC counterpart).

(a) Monthly maximum occurrence tables: 12 tables.

(b) Monthly minimum occurrence tables: 12 tables.

(c) Annual maximum table: 1 table.

(d) Annual minimum table: 1 table.

(4) Wave height duration chronology graphs: No graphs or tables of this type appear ever to have been published. A given graph should show chronologically for the 25 or 28 year period all intervals during which the wave height at the deep-water station equalled or exceeded a given height. These waves cannot be carried into shoal water without accompanying period and direction information. When judiciously used, however, these graphs will serve as a coarse guide to wave height durations to be expected in shoal water; they will also be useful for identifying intervals of a few days to weeks of anomalously high and low wave heights that appear to occur with high regularity at specific times of the year. Construct the graph in the form of an interrupted bar graph, with ordinates being days of the year versus years; run the days of the year from 1 July through 30 June so as not to break duration bars in the mid-winter wave season; a given bar should incorporate or connect all successive FNWC analyses where the wave height equals or exceeds a selected value; construct separate graphs for $H \geq$ 4 feet, 8 feet, 12 feet, etc. (or at one meter intervals); the number of occurrences of waves in excess of a given height through the years should

be summed for each day. The wave analysis interval (12 and 24 hours) can be mixed in creating this graph, although the interval should be identified for the user. Construct each graph from FNWC combined sea and swell analyses only.

(5) Extreme wave event listing: Design wave heights for coastal structures are determined from hindcasted or observed infrequently occurring large wave heights (i.e., from small-sample statistics). This table identifies the synoptic weather events producing high waves so that the wave characteristics associated with each event can be examined individually and in relation to the meteorological conditions generating them. Print out in chronological order for the 28-year period the following information for all occurrences where $H \geq 15$ feet (or 5 meters) for sea, swell, and combined sea and swell: (i) Coastal station, (ii) Analysis date and time, and (iii) Wave height, period, and direction.

b. Wave-type tabulations: Compile separately all tables/graphs listed in Section 4a from FNWC sea analyses, swell analyses, and combined sea and swell analyses, except where otherwise indicated; it may be noted that the NMC tables contain no counterpart of the FNWC combined sea and swell data.

c. H-T-ψ tabulation increments and intervals: The following specifications apply primarily to the frequency-of-occurrence tables described in Sections 4a(1), (2), and (3).

(1) Height: Compile the wave statistics in odd 2-foot height increments (as in the NMC tables) over the full height range of the FNWC data (it should be noted that swell heights less than 3 feet were discarded in the FNWC singular wave program). Consider presenting wave height in metric units on the basis of expected practice or edict; if metric units are used, the wave height increment used in the frequency-of-occurrence tables should be 1/2 meter from 0 to 3 m and 1 meter above 3 m. The height parameter appearing in all statistical presentations should be the significant height.

(2) Period: Compile the statistics in even 2-second increments (as in the NMC tables) over the full range of the FNWC data, beginning at 4 seconds for all three wave types.

(3) Direction: The NMC statistics are compiled in a directional bandwidth of $22\frac{1}{2}^{\circ}$; users find this coarse increment to be generally limiting and sometimes unsatisfactory for refraction purposes along the California coast. The FNWC singular wave directions

are reported at a 10° interval; each interval value can be considered the center of a 10° direction bandwidth. Accordingly, the wave statistics should be compiled for direction bandwidths of either 10° or 20°. The choice of a 10° bandwidth clearly would be more desirable for refraction purposes but would double the volume of the tables to be produced; nevertheless, compilation of the statistics at 10° intervals is recommended.

d. Frequency-of-occurrence values: The following specifications apply only to the tables described in Sections 4a(1), (2), and (3).

(1) Number of occurrences: Express the frequency-of-occurrence values in these tables as the number of FNWC analyses occurring in the tabulation period being considered (e.g., in a specific 30-day month the number of 12 hourly FNWC analyses totals 60); this is different from the NMC report where the frequency of occurrence is given in percent.

(2) Hours and percent of occurrence: For the long-term mean tabulations only (Section 4a(1)), which are large-sample tabulations, print conversion factors on each table so that the number-of-occurrence values can be converted into hours or percent of the

period being considered. Include in all tables the frequency of occurrence of calms (as in the NMC tables); do not include "offshore" waves (as is done in the NMC tables); sum the occurrences vertically and horizontally (as in the NMC tables).

e. Total frequency of occurrence: Because of the design of the FNWC singular wave program, the total occurrence in all tables of sea, swell, and combined sea and swell must be equivalent to 100% (e.g., for a 30-day month of wave statistics compiled from FNWC 12-hourly analyses the occurrence total must be 60 for sea, 60 for swell, and 60 for combined waves); users of the NMC statistics are aware that the total for swell exceeds 100% of the period under consideration.

f. Computer printouts: Produce camera-ready computer printouts of all statistical tables and chronological data in the most compact form possible for reproduction as easily legible, desk-top, hard copy.

REFERENCES

1. National Marine Consultants, 1960
Wave Statistics for Seven Deep Water Stations along the California Coast
Prepared for the U. S. Army Corps of Engineers, Los Angeles and San Francisco Districts

2. Marine Advisers, 1961
A Statistical Survey of Ocean Wave Characteristics in Southern California Waters
Prepared for the U. S. Army Corps of Engineers, Los Angeles District

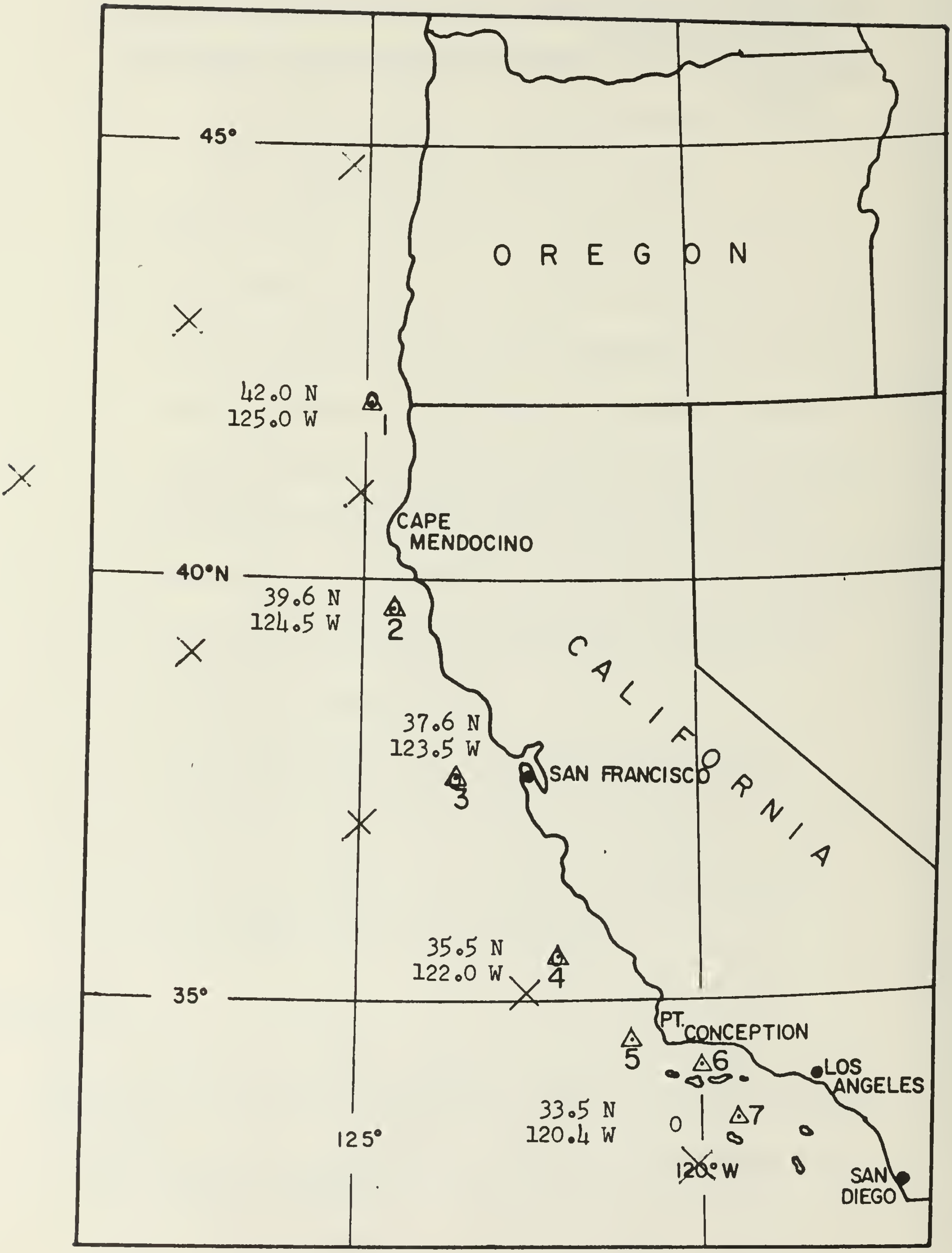

FIGURE I: LOCATION OF HINDCAST STATIONS 31.5 N 118.4 W 0

△ NMC Stations
X FNWC Grid Points (approximate)
0 Proposed Stations

TABLE 3.13 AVERAGE Annual HEIGHT-PERIOD-DIRECTION FREQUENCY DISTRIBUTION (PERCENT)[1] STATION 3 (1956,1957,1958)

SWELL AVERAGE TOTAL HOURS 10,253.56

DIR.	NNW							NW							WNW						
H_s \ T_s	6-8	8-10	10-12	12-14	14-16	16-18	18+	6-8	8-10	10-12	12-14	14-16	16-18	18+	6-8	8-10	10-12	12-14	14-16	16-18	18+
1-2.9	.43	.96	.17	.13	.02	.05		2.76	9.68	8.41	1.33	.82	.04	.02	2.92	6.93	2.74	1.22	.83	.35	.25
3-4.9	.12	.49	.29	.16	.07	.05		1.59	5.83	2.75	1.29	.45	.20	.02	1.47	4.98	3.16	1.64	.89	.72	.07
5-6.9		.16	.12	.12	.09			.07	2.20	1.49	.57	.27	.14		.07	1.93	2.20	1.07	.61	.23	.05
7-8.9		.02	.07	.02					.43	.90	.32	.22	.07			.42	1.14	.62	.23	.09	
9-10.9			.07						.07	.39	.24	.21	.05			.09	.32	.27	.09		
11-12.9									.02	.17	.24	.07	.07				.18	.09	.02	.05	
13-14.9										.10	.25	.07					.05	.09	.07		
15-16.9											.02	.02						.07	.04		
17-18.9											.07						.02				
19-20.9																				.02	
21-22.9																					
23-24.9																					
25-26.9																					
27 +																					
Σ	.55	1.63	.72	.43	.18	.10		4.42	18.23	14.21	4.33	2.13	.60	.04	4.46	14.35	9.80	5.07	2.79	1.46	.37

DIR.	W							WSW							SW						
H_s \ T_s	6-8	8-10	10-12	12-14	14-16	16-18	18+	6-8	8-10	10-12	12-14	14-16	16-18	18+	6-8	8-10	10-12	12-14	14-16	16-18	18+
1-2.9	1.53	2.96	2.19	1.02	.41	.10	.02	.64	.86	.53	.12	.10			.09	.94	.23				
3-4.9	1.40	2.73	1.82	.53	.35	.10	.02	.46	.57	.29	.17				.07	.09					
5-6.9	.23	1.75	1.10	.50	.36	.13		.05	.43	.17	.07					.12	.02	.05			
7-8.9	.02	.44	.55	.48	.14				.14	.12	.05					.02	.05	.02			
9-10.9		.12	.38	.18	.05				.02	.10	.05		.02			.05					
11-12.9		.10	.42	.12	.07	.02			.05	.12	.02										
13-14.9			.05	.10	.02					.02											
15-16.9			.13	.02						.02	.02		.02								
17-18.9			.05	.05	.02						.02	.02									
19-20.9				.05	.02	.02					.02										
21-22.9																					
23-24.9				.05	.02	.02															
25-26.9																					
27 +																					
Σ	3.18	8.10	6.69	3.10	1.46	.39	.04	1.15	2.07	1.37	.54	.12	.04		.16	1.22	.30	.07			

DIR.	SSW							S							SSE							Σ
H_s \ T_s	6-8	8-10	10-12	12-14	14-16	16-18	18+	6-8	8-10	10-12	12-14	14-16	16-18	18+	6-8	8-10	10-12	12-14	14-16	16-18	18+	
1-2.9	.02							.02	.04	.04							.04	.02	.02			52.03
3-4.9	.07	.16						.12	.07	.11	.02					.02						35.41
5-6.9		.05			.02			.05	.02			.02										16.53
7-8.9			.02	.02					.07		.02											6.71
9-10.9									.02	.05												2.84
11-12.9																						1.83
13-14.9																						.82
15-16.9																						.36
17-18.9																						.25
19-20.9																						.13
21-22.9																						
23-24.9																						.09
25-26.9																						
27 +																						
Σ	.09	.21	.02	.02	.02			.19	.22	.20	.04	.02				.02	.04	.02	.02			117.00

19

SEA

DIR.	N					NNW					NW					WNW				
H_s \ T_s	4-6	6-8	8-10	10-12	12+	4-6	6-8	8-10	10-12	12+	4-6	6-8	8-10	10-12	12+	4-6	6-8	8-10	10-12	12+
1-2.9	.02					2.18	.09				11.17	.52	.02			1.98	.02			
3-4.9	.02	.02				.58	2.39	.05			1.99	12.14	.23			.58	1.54	.10		
5-6.9		.02					.79	.33				3.17	1.04			.07	.37	.02		
7-8.9								1.51				.09	5.71				.05	.28		
9-10.9								.31	.17				1.22	.13			.02			
11-12.9								.02	.45				.09	.26						
13-14.9														.15						
15-16.9									.09					.14						
17-18.9																				
19 +																				
Σ	.04	.04				2.76	3.27	2.22	.71		13.16	15.92	8.31	.68		2.63	2.00	.40		

DIR.	W					WSW					SW					SSW				
H_s \ T_s	4-6	6-8	8-10	10-12	12+	4-6	6-8	8-10	10-12	12+	4-6	6-8	8-10	10-12	12+	4-6	6-8	8-10	10-12	12+
1-2.9	2.66	.12				.53					2.14	.05				.18				
3-4.9	.66	.85				.17	.42	.02			.40	1.29	.05			.15	.36			
5-6.9		.14	.02				.09					.12	.07	.02			.14	.02		
7-8.9			.20					.16				.02	.32				.04	.21		
9-10.9													.02					.09	.02	
11-12.9								.07					.02					.05	.05	
13-14.9														.05					.14	
15-16.9																			.05	
17-18.9																				
19 +																				
Σ	3.32	1.11	.22			.70	.51	.25			2.54	1.48	.48	.07		.33	.54	.37	.26	

DIR.	S					SSE					OFFSHORE	CALM[2]	Σ
H_s \ T_s	4-6	6-8	8-10	10-12	12	4-6	6-8	8-10	10-12	12+			
1-2.9	1.99					1.05							24.72
3-4.9	.35	1.23	.10			.11	.62	.07					26.49
5-6.9		.33	.05				.24						7.05
7-8.9			.88				.18	.27	.02				9.94
9-10.9			.10	.02				.17					2.27
11-12.9			.14	.12					.02				1.29
13-14.9			.05	.16				.02	.07				.64
15-16.9			.02	.02					.02				.34
17-18.9				.02									.02
19 +													
											.94	26.30	27.24
Σ	2.34	1.56	1.34	.34		1.16	1.04	.53	.13		.94	26.30	100.00

1 Based on 365-1/3 Days

2 Includes waves of 0 to 0.9 feet

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